Changes in dominance of dipteran families on Coral Sea cays over ten years during a period of substantial vegetation change

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Abstract

The habitat on the Coringa-Herald group of coral cays within the northern Coral Sea underwent profound change after about 2000 because of extensive dieback of the dominant forest trees. This work summarises surveys on these cays in 1995, 1996, 1997 and 2007, in order to understand the effect on the native insect fauna of the introduced biological control agent, the non-specific predatory ladybird beetle *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae), that was liberated to control scale insects (Hemiptera: Coccidae) whose infestation was responsible for the dieback of the forest trees. This paper documents the families of Diptera (flies) collected on the surveys and it records changes in presence and abundance of Chloropidae, Phoridae, Sarcophagidae, Canacidae, Lonchaeidae and Chironomidae sampled in pitfall traps and yellow pans. Despite some differences in collecting methods and seasons between surveys, there is evidence of substantial changes in the presence and relative abundance of these families. The decline of several families on Coringa Cay and on North East Herald Cay between 1995/96 and 2007 could be the result of a trophic cascade of species loss following tree dieback. One of the most conspicuous changes was that Chloropidae increased on North East Herald Cay between 1997 and 2007 following increases in populations of scale insects, but chloropids are not thought to have had a direct role in the control of scale insects.

Introduction

The Coringa-Herald group of coral cays is located 450 km east of Cairns in the northern Coral Sea (Figure 1). They are part of the Coral Sea Conservation Zone, are a National Nature Reserve, and are protected as an IUCN Nature Reserve because of their importance as nesting grounds for endangered sea birds and turtles. Seventeen of the 27 bird species recorded from the Coral Sea Conservation Zone are

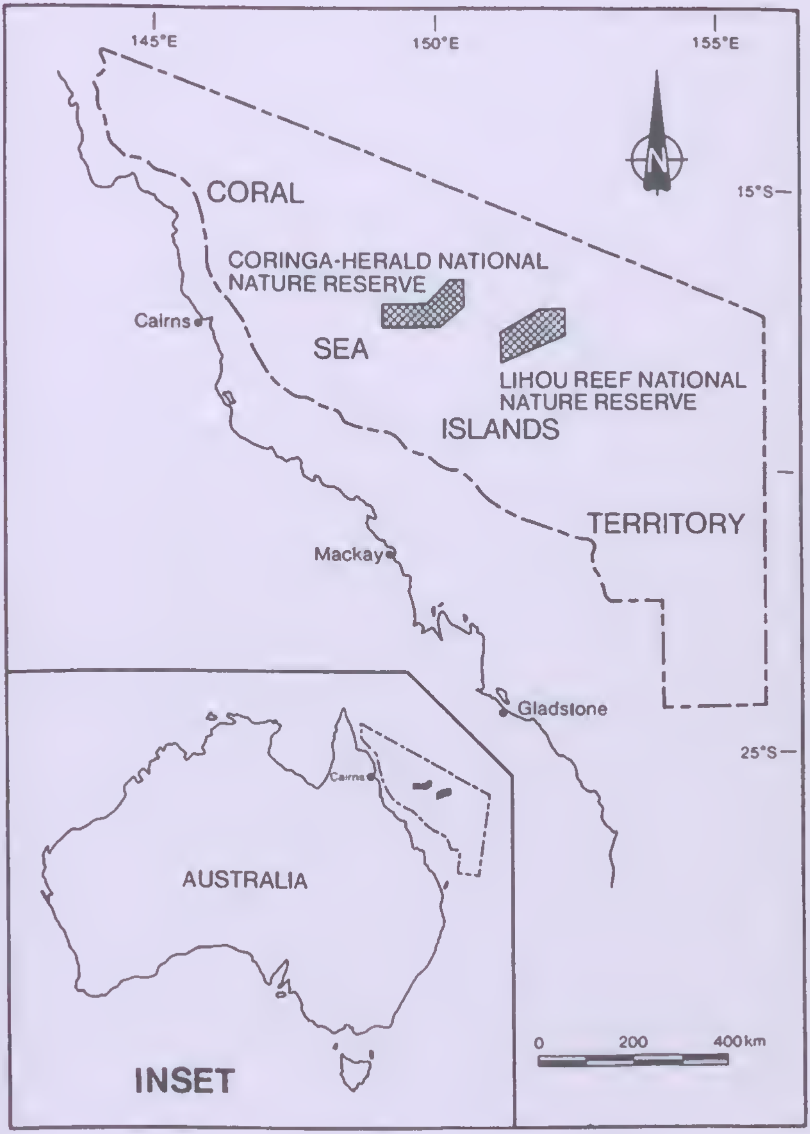

Figure 1. Map of the Coral Sea Islands Territory showing the location of the Coringa-Herald National Nature Reserve.

listed under the Japan/Australia Migratory Birds Agreement and the China/Australia Migratory Birds Agreement. This means that Australia has an obligation to protect the nesting sites of the listed migratory and endangered bird species on those cays. Their nesting sites are in the trees on these cays and beneath them on the ground. Several species of bird, notably Black Noddies (*Anous minutus*) and Mutton Birds (*Puffinus pacificus*), depend for nesting on *Pisonia grandis* trees, originally present on three cays – North East Herald, Coringa and Magdaleine (Handler *et al.* 2007, Greenslade 2008, Hoffman & Kay 2008, Hill *et al.* 2003). In 2001, the *Pisonia* trees suffered extensive dieback on North East Herald Cay and they had nearly disappeared on Coringa Cay due to the impact of the sap-feeding scale insect *Pulvinaria urbicola* (Hemiptera: Coccidae) (Figure 2). An ant-scale mutualism that facilitated the multiplication of the scale was suggested as the main factor involved in the dieback (Smith *et al.* 2004). The Australian Department of the Environment, Water, Heritage and the Arts decided to introduce the non-specific predatory ladybird *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae) to control the scale insect and thus reduce *Pisonia* dieback and in doing so reduce the numbers of 'tramp ants'. This term relates to species of ant that have spread, and are still dispersing from their original location usually into tropical areas, mediated by human movements. They tend to be pest species, not only for economic but also social reasons.

The impacts on the insect faunas as a result of the invasions by the tramp ants as well as the release of the ladybird beetle were unknown because the faunal composition on the cays prior to these events had not been comprehensively sampled or the data analysed and presented. As a first step, Greenslade (2007) summarised unpublished results of three invertebrate surveys carried out opportunistically in 1995, 1996 and 1997 before the onset of the *Pisonia* dieback and the rise of the tramp ants. Subsequently, in 2007 the second author and Roger Farrow undertook a survey for invertebrates on all four cays within the Coringa-Herald group and summarised the results from all the surveys (Greenslade & Farrow 2008).

Greenslade & Farrow (2008) found that the cays supported a diverse insect fauna, and that between 1995 and 2007 some species of the families Formicidae (ants) and Coccidae (scale insects) showed significant increases in overall numbers suggesting that an ant-scale mutualism was indeed responsible for the abundance of the scale and the consequent dieback of its *Pisonia* host (Greenslade & Farrow 2008, Greenslade 2010). At the same time, an overall decline in species richness and abundance of other insect species was recorded on the cays before the dieback (Greenslade 2008, 2010), although not all taxa from these surveys were able to be identified and counted to family level (Greenslade & Farrow 2008). One key group, not identified by these authors beyond the level of order, was Diptera (flies). As this group was abundant and species-rich in the collections, it was considered valuable to identify dipteran families and count individuals in each family, along with establishing the timelines of their population shifts. This analysis was done to test the hypothesis that changes in populations of the dipteran families were correlated with *Pisonia* dieback, with the main aim being to provide additional information on the effects of *Pisonia* dieback and tramp ant invasion on the assemblages of native insects on these isolated coral cays. Furthermore, because of the difficulty of access to these cays and the limited opportunities to collect insects there, a record of the Diptera present at different times over this 12 year period is a useful baseline for future environmental surveys.

Adult Diptera from all the surveys had been sorted to order prior to the analysis reported here. A superficial examination of these collections indicated that the abundance and dominance of species caught in both the pitfall traps and the yellow pans had changed between 1997 and 2007 (Greenslade & Farrow 2008).

Figure 2. Photograph showing the habitat on North East Herald Cay in May 2007. Note dead *Pisonia grandis* trees that had previously formed the canopy and understorey of recently established, opportunistic *Abutilon indicum* shrubs exploiting the light gaps created by the death of the *Pisonia* trees. (Penelope Greenslade)

That initial sorting was carried out by the second author and the specimens were subsequently allocated to family by the first author at The Australian Museum under the guidance of the third author. This paper reports on the identification and relative abundance of selected dipteran families to provide a possible explanation of the observed changes over time including consideration of the influence, if any, of the *Pisonia* dieback and tramp ant presence.

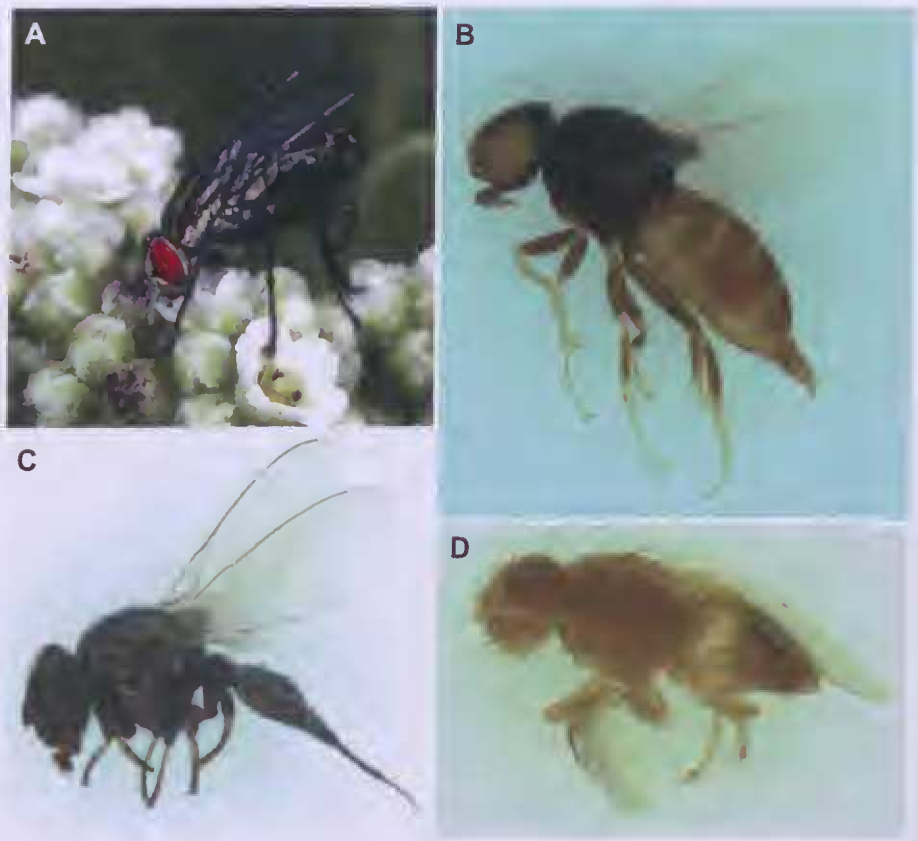

Figure 3. Representative species of Diptera dominating samples from North East Herald Cay: **A.** Sarcophagidae, here shown feeding on flowers of Octopus Bush (*Argusia argentea*) (Chris Freebairn); **B.** Chloropidae (John Martin); **C.** Lonchaeidae (John Martin); **D.** Canacidae (John Martin).

The mean temperatures at the Coringa-Herald group are similar between March and May, with March being at the end of the wet season and May the start of the dry season. The mean diurnal temperature range and rainfall for March from 1981–2010 was 25.6–29.7 °C and 214.2 mm, respectively (BOM 2011 for Willis Island). The mean temperature range and rainfall for May from 1981–2010 was 24.2–27.8 °C and 91.8 mm, respectively (BOM 2011). This group of cays experiences a cyclone roughly every 20 years. In 1989 Tropical Cyclone Airvu caused extensive damage, but the evidence of this cyclone was not obvious at the time of the 2007 survey. Cyclone Yasi also caused extensive damage when it struck in 2011, but since no invertebrate monitoring had been undertaken since 2007, the effects are unknown.

Methods

The Diptera came from the following four surveys (see Table 1), each being described in greater detail by Greenslade & Farrow (2008). The 1995 and 1996 surveys were conducted in March and consisted of various trapping methods on North East Herald Cay and Coringa Cay over approximately one month. The 1997 survey was conducted in May and consisted of various trapping methods on North East Herald Cay over a period of approximately one week. Samples identified from pitfall and yellow pan catches are summed for all methods and dates within each year. The 2007 survey was conducted in May over four days and consisted of various trapping methods on North East Herald Cay and South West Herald Cay, but pitfall traps were only deployed for two days on Magdaleine and Coringa Cays. The pitfalls and yellow pans used were identical to those used in the 1997 survey, so the numbers of insects per trap day were strictly comparable.

Dichotomous keys from the *Manual of Nearctic Diptera* (McAlpine 1981, 1987) and *Insects of Australia* (CSIRO 1991) were used to identify adult Diptera specimens, which had been stored in 70% ethanol. All the specimens resulting from these surveys are deposited in the Australian Museum in Sydney.

Data analysis

All dipteran specimens from the 1995, 1996, 1997 and 2007 surveys were identified to family (Table 1). The data shown in that table are the number of individuals in each family for each collection event. For this summary the 1995 data were amalgamated with the 1996 data because of the small number of specimens collected in 1996, and the fact that the collections were made by the same group of researchers at the same time of year. No statistical tests were performed because the variation in collection methods, timing and duration between the surveys resulted in incomparable data sets, and the number of traps from which the flies were taken was not recorded in the 1995 and 1996 surveys.

Table 1. Numbers of Diptera in each family collected from four Coral Sea Islands in years from 1995 to 2007. Percentages are given in brackets after the absolute number of individuals. Only values of 1% or more given.

Family	North East Herald			South West Herald			Coringa			Magdaleine		
DATES	1995/6	1997	2007	1995/6	1997	2007	1995/6	1997	2007	1995/6	1997	2007
Sarcophagidae	2	2	316(78)						8			
Lonchaeidae	60(14)	3	1			1	504(47)					1
Chloropidae	18(4)	2	35(9)			14	14(1)					
Canacidae	162(38)	0	18(4)			4	429(41)					
Phoridae	28(6)	0	30(7)			1	21(2)					
Mycetophilidae	6(1)	0	0				54(5)					
Ephydridae	45(10)	0	0				2					
Muscidae	0	0	0				4					
Calliphoridae	3	2	2				1					
Pipunculidae	1	1	2			6	1					
Lauxaniidae	43(10)	0	0				23(2)					
Cecidomyiidae	2	0	3			2	3			1		
Hippoboscidae	2	2	0				1					
Dolichopodidae	1	0	0									
Stratiomyidae	23(5)	0	0				14(1)					
Chironomidae	35(8)	0	0				2					
Ceratipogonidae	1	0	0									
Total individuals	**432**	**12**	**407**	**0**	**0**	**28**	**1073**	**0**	**8**	**1**	**0**	**1**
Total families	**16**	**6**	**8**	**0**	**0**	**6**	**14**	**0**	**1**	**1**	**0**	**1**

Results

The survey data, at least from North East Herald Cay and also to a more limited extent from the other three cays, allows the relative abundance of dipteran families between years and families to be reported here with confidence as to their reliability and relevance to other biotic changes that took place over the 10 year period between the survey years.

North East Herald Cay families

The total number of dipteran families found on North East Herald Cay over all years was 16. This number is quite small considering that there are nearly 100 families of Diptera in Australia (CSIRO 1991). In 1997 representatives of six families were collected on North East Herald Cay, and in 2007 eight families recorded (Table 1). The composition by family and number of individuals also differed; three families that were present in 2007 (i.e. Phoridae (commonly known as scuttle flies), Canacidae (beach flies) (Figure 3D) and Cecidomyidae (gall midges)), were not present in 1997, and eight families (i.e. Chironomidae (non-biting midges), Mycetophilidae (fungus gnats), Ephrydidae, (brine flies), Lauxaniidae, Hippoboscidae (louse flies), Dolichopodidae (longlegged flies), Stratiomyidae (soldier flies) and Ceratopoconidae (sand flies)) were present in 1995/96, but absent in 2007 (Table 1).

Dominance on North East Herald Cay in 1995, 1997 and 2007

The numerically dominant families in terms of relative abundance on North East Herald Cay were different in each of the sampling periods (Table 1). In 1995/96 Canacidae were dominant comprising 38% of individuals caught, with the next most dominant family being Lonchaeidae (lance flies) (Figure 3C) with 14% individuals (Table 1). In 2007 Sarcophagidae (flesh flies) (Figure 3A) were dominant with 77% of the dipteran population (Table 1).

Coringa Cay 1995/96 and 2007

On Coringa Cay in 1995/96 the most abundant families caught were Lonchaeidae at 47% and Canacidae at 40%, with various other families comprising the remaining 13 % (Table 1). In 2007 only Sarcophagidae were collected, but only eight individuals from this family were trapped (Table 1). As these flies may have been attracted to the preservative in the traps, drawing wider inferences on the Coringa Cay dipteran population in 2007 is not possible.

Discussion

Large shifts in the populations of flies are considered as useful baseline data which provide direction for future research on the environment of these ecologically important coral cays. Although the composition of the dipteran populations did change in synchrony with the dieback of the dominant trees, differences in collection sites, methods, and seasons between collections in 1995/96 and the two later surveys means that the hypothesis that population shifts of Diptera actually correlate with tree dieback cannot be tested statistically. Nonetheless, some changes are obvious in some families. For instance, the abundance of Loncheidae on North East Herald Cay was high in 95/96, but low in later years. And it appeared that the dominant dipteran families did change in parallel with *Pisonia* tree dieback, release of the biological control agent, and increases in populations of scale insects and tramp ants on North East Herald Cay and Coringa Cay, but whether these latter factors are directly related to fly abundance is unlikely. Another factor that would influence the samples is migration to and from the cays (Farrow 1984). As the dipteran families recorded here are not known to be specialised for long distance migration, the most likely climatic event that would permit them to disperse to the cays are cyclones.

North East Herald Cay

In 2007 members of the family Sarcophagidae were the dominant flies in traps with 77% of total abundance (Table 1). Greenslade & Farrow (2008) noted that an adult sea turtle carcass was present on the cay at that time. The turtle had become trapped in a coastal shrub and died. A species of hide beetle, *Dermestes ater* (Coleoptera: Cleridae), inhabited the turtle carcass, and fly larvae were found in an adjacent turtle egg clutch (Greenslade & Farrow 2008). Sarcophagid larvae live and breed in freshly decomposing flesh (CSIRO 1991), and the succession of insects on carcasses usually begins with larval Diptera before progressing to Coleoptera as decay progresses (Amendt *et al.* 2004). The relative dominance of Coleoptera in the carcass in 2007 is probably evidence of the age of the carcass with the adult sarcophagids already having emerged. Turtle strandings are assumed to occur rarely on small coral cays, and therefore, the high number of adult sarcophagids recorded in 2007 is most likely because of this serendipitous bounty. As such, it is unlikely that the change in numbers of sarcophagids from 1997 is related to *Pisonia* dieback.

Excluding sarcophagids, three other families of flies assume co-dominance in terms of abundance – Chloropidae (38%), Phoridae (32%) and Canacidae (20%) – together making up 90% of the fauna (Table 1). The 2007 data show four major differences from the earlier collections (Table 1). The most dominant family in 1995/96, Chironomidae (midges), was absent in 2007 (Table 1). Chloropidae (frit flies) (Figure 3B) showed an approximately 2.8-fold increase in dominance from 1997 to become the most dominant family in 2007 (Table 1). Phoridae (scuttle or hump-backed flies), which were absent in 1997 but present in 1995/96, appeared in the 2007 collection as the second most dominant family at 32 % (Table 1). Alternatively, Lonchaeidae showed a 14-fold decrease to become the least dominant family in 2007 (Table 1). Canacidae (shore flies) increased in relative representation in 2007 from 1997, but were abundant in 1995/96. This difference may be related to a change in resources along the shoreline for this family.

Absence of Chironomidae in 2007

Chironomidae are aquatic insects, and one subfamily, Clunioninae, inhabits intertidal marine environments (Ferrar 1987). Thus the chironomid life cycle is independent of tree habitats and associated animals, and its absence from the 2007 collection is not likely to be a result of ecological shift as a result of *Pisonia* dieback. It is more likely that collections were undertaken during a time when chironomids were absent as adults. Larval stages of chironomids can last from a few days to more than a year and the emergence of adults is largely dependent on weather and lunar cycles (Ferrar 1987; Macintosh *et al.* 2008). The survey on North East Herald Cay in 1995/96 was over a longer period than the 2007 survey, so that timing or seasonal migration may have been the reason why this family was absent from collections in 2007.

Increase of Chloropidae in 2007

Chloropidae have a wide range of larval habits. The chloropids encountered on South West Herald Cay are members of the subfamily Oscinellinae, several members of which are known to prey on scale insects (Ferrar 1987). Numbers of scale insects were approximately 50-fold fewer in 1997 and earlier than in 2007 (Smith & Papecek 2001a, Smith & Papecek 2001b), which coincides with the changes in relative abundance of chloropids (Table 1). However, chloropids were also found in relatively high numbers on South West Herald Cay, where *Pisonia* trees are now completely absent (Batianoff *et al.* 2010). There were at least three different chloropid species present in the collections so, whilst it is possible that the particular species on North East Herald Cay might be parasitising scale insects, the unidentified species on South West Herald Cay might not. Furthermore, because chloropids were present prior to the scale outbreak, there is no clear indication that those on North East Herald Cay played a major role in controlling numbers of scale insects. Their role in control of the scale insects is further brought into question because of the rapid decline of the scale insects in 2002, directly after the introduction of the biological control agent (Smith & Papecek 2001a, Smith & Papecek 2001b). Identification of all chloropids to species level would improve our understanding of invertebrate-invertebrate interactions on these cays. In particular, such information would add to the comprehensiveness of any assessment pertaining to the ladybird beetle release and effectiveness.

Appearance of Phoridae in 2007

A few species of Phoridae are known to parasitise species of the beetle family Coccinellidae and others are associated with ants (Ferrar 1987). Although phorids were present in 1995/96, they were absent in 1997 despite a moderate ant population (Table 1) (Greenslade & Farrow 2008). The North East Herald Cay Phoridae have been identified more precisely and they include one specimen of the genus *Dohrniphora* which could not be identified to species level as it was a female. The other specimens (nearly 100 individuals from North East Herald Cay and Coringa Cay) all belong to *Megaselia spiracularis*, a new record for Australia (Disney & Greenslade 2012), so there would have been no interaction of phorids with the introduced ladybird *Cryptolaemus montrouzieri* or with the dominant and recently invading ant species *Tetramorium bicarinatum*. As *M. spiracularis* is saprophagous, its appearance in 2007 is possibly associated with the turtle carcass on North East Herald Cay.

Decline of Lonchaeidae

Members of the Lonchaeidae are most often secondary invaders of fruit after other insects have already laid their eggs or after mechanical damage to the fruit has occurred. As a result they can initiate decay (Ferrar 1987). However, the larvae of many species have also been found in association with wood boring Coleoptera, where they live in galleries excavated by the beetles and feed on dead beetle larvae (Ferrar 1987). Because *Pisonia grandis* is one of the only two fruit-bearing woody trees on North East Herald Cay (Batianoff *et al.* 2010), it is possible that the lonchaeids were dependent on either *Pisonia* fruit or on an association with wood-boring Coleoptera found in rotting timber. After the dieback in 2001, recruitment of *Pisonia* trees by seedlings was low (Burger 2005) and tree densities had not returned to 1997 levels by 2007. Therefore, the 14-fold lonchaeid population decline (when sarcophagids were omitted) (Table 1) may be due to loss of fruit hosts rather than to wood borers. The latter would be expected to increase with the death of trees. Further identification and future surveys would help explain the role of loncheids on these cays, and improve our understanding of trophic cascades when a single plant species is lost from an ecosystem.

Data from Coringa Cay can also be used to support the hypothesis that declines in the lonchaeid populations were the result of dieback. In 1995/96, when *Pisonia* trees were still present on Coringa Cay, the Lonchaeidae was the most dominant family (Table 1). In 2007, after the *Pisonia* trees had died and so had been absent from this cay for six years (Greenslade 2010), the Lonchaeidae were absent from collections (Table 1). Whilst the 1995 survey was conducted in the wet season and the 2007 survey was conducted in the dry season and was of short and limited duration, data between wet and dry seasons from North East Herald Cay show no change in lonchaeid dominance (Table 1). This suggests that the seasonal difference between collections is unlikely to have had an effect on lonchaeid populations. *Pisonia* dieback was therefore likely to be the cause of lonchaeid population declines on both North East Herald Cay and Coringa Cay.

Conclusions

Of the six families of flies to have notable population changes in synchrony with the invasion of the invasive tramp ants, *Pisonia* dieback, and deliberate release of the predatory ladybird beetle, four (i.e. Sarcophadidae, Phoridae, Canacidae and Chironomidae) are thought not to have any correlation with any of these events. In particular, the populations of Phoridae and Sarcophagidae are almost certainly related to the death of a sea turtle on North East Herald Cay as well as to the possible presence of other avian corpses. There is no indication that the introduction of the ladybird beetle affected fly populations, although the effect of the invasive ant *Tetramorium bicarinatum* on fly larvae is unknown.

The two families of flies that showed large changes in abundance after the dieback of the *Pisonia* trees, and that also have an ecological relationship with the terrestrial vegetation, were Chloropidae and Lonchaeidae. The population increases of chloropids on North East Herald Cay between 1997 and 2007 can be associated with increases in the population of scale insects. However, these flies are not thought to have a significant role in control of scale insects because they were present before the scale outbreak, and notable scale decreases occurred after the release of a predatory beetle that feeds on the scale insects. There were at least two species of chloropid in the collections leaving ambiguities with respect to the role of certain chloropids at specific times and on different cays. To be comprehensive in the assessment of the effects of the ladybird beetle on both the scale population and native fauna, all the chloropid species should be examined and identified. The relative population changes of Lonchaeidae could be an indicator of the loss of fruiting trees as well as of the invasive ant abundance (Greenslade 2008); the latter caused a trophic cascade of species loss following *Pisonia grandis* dieback and *Cordia subcordata* defoliation. As the relative abundance of Lonchaeidae changed in synchrony with *Pisonia* dieback, two scenarios are suggested – either these lonchaeids are dependent on *Pisonia* fruit, or that the loss of the *Pisonia* trees caused a trophic cascade of species loss on Coringa Cay.

Due to the incomparable data sets, the conclusions drawn here are mostly speculative. However, as baseline data, the data provided here provide a starting point for future research in the conservation of these globally important environments.

Acknowledgements

Fieldwork in 2007 was supported by the then Department of the Environment, Water, Heritage and the Arts. DR's study was part of her second year degree work at the University of Sydney. The authors are grateful to both referees for valuable comments on an earlier version of this manuscript.

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